



# Challenges in Construction of Secant Bored Piles in Sandy Soil and Within a Railway Protection Zone

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**Abstract** The continuing growth of population density in urban areas around the world has placed greater emphasis on the utilisation and development of underground space to meet the increasing demands of the city. Due to limited land space available in downtown areas, many cities in the world are also embarking on integration of major construction projects of metro infrastructure, commercial developments and residential estates, etc., to meet the growing demand of infrastructure. In land-scarce Singapore, the development of a comprehensive and well-integrated public transport network is important to achieve a people-centric, world-class transport system. To enhance the connectivity of a rail network, interchange stations and underground linkways are constructed to connect the various lines so that transfers between mass rapid transit (MRT) lines can be seamless. Hence, it is becoming more challenging to construct a new MRT line in the vicinity of existing MRT lines without impacting the operations of existing MRT lines. The prime aim of this study is to present the ways to overcome the challenges in construction of secant bored piles (SBPs) above the existing underground MRT linkway (15 m below ground) and adjacent to the existing underground MRT East West Line station. The paper presents four different techniques applied to construct the SBP wall in the sandy soil since the conventional method of construction was not applicable to the site condition. The new techniques were successful as the SBP wall was constructed while keeping the vibrations

and movement to the existing MRT structures within the allowable limits. From this venture, it can be concluded that it is possible to install SBPs in sandy soils without any significant impact on adjacent structures and construction timeline. The experience gained from this endeavour will be invaluable and can serve as lessons learnt for SBP works in the densely populated area and in the vicinity of existing sensitive structures which is increasingly becoming unavoidable.

**Keywords** Secant bored pile · Retaining wall · Sandy soil

## 1 Introduction

The Thomson-East Coast Line (TEL) in Singapore is an underground mass rapid transit (MRT) system along the north–south corridor and eastward along the east coast of approximately 43 km. It consists of 31 MRT stations and an integrated MRT cum bus depot at Mandai. Contract T222 includes the construction of the Outram Park Station box and entrances and integration of an extensive network of linkways to the existing East West Line (EWL) and North East Line (NEL) stations, and two pairs of TEL bored tunnels to Maxwell and Havelock stations. Figure 1 shows the site location of contract T222.

To cater for the demand of anticipated increased ridership at Outram Park due to three MRT lines, an extensive network of linkways is constructed to connect the three stations at basement 1 and basement 3 levels. This paper will present the case study and challenges in the construction of retaining walls for the construction of the underground linkway (zone G) in close proximity to the existing EWL line and directly above the EWL–NEL linkway [1]. Figure 2 shows the location of zone G.

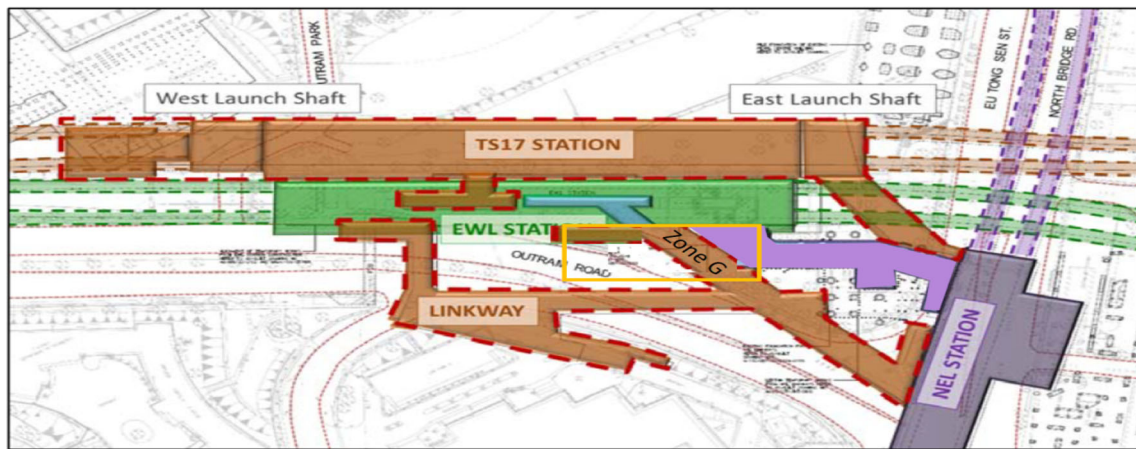
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**Fig. 1** Site plan of the project



**Fig. 2** Location of zone G

Green and blue colour shows the boundary of existing EWL and NEL lines, respectively. The extent of the new construction under T222 is demarcated in brown colour in Fig. 2. Zone G is constructed to enhance the rail connectivity among the three lines (EWL, NEL and TEL).

## 2 The Soil Profile

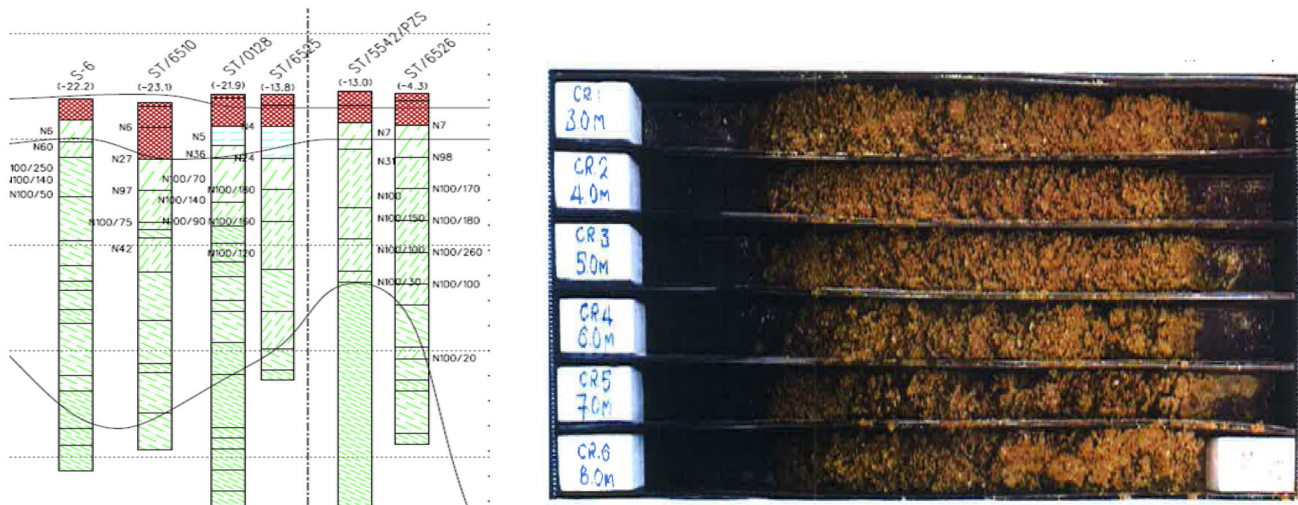
Before starting the works for the secant bored piles (SBPs), subsoil investigation (SI) was done to understand the soil parameters, including bearing capacity, type, character and nature of the soil, and to allow the designer to design the pile according to soil properties [2]. Figure 3 shows the geological profile at the location of zone G obtained from subsoil investigation.

Historical soil investigation data showed that the geology here consists of fill material approximately 2 to 5 m thick overlying the soil and sedimentary rocks of the Jurong formation. However, during the SI works near the

existing structures, loose sand was encountered at some locations up to a depth of 13 m.

## 3 Stakeholders

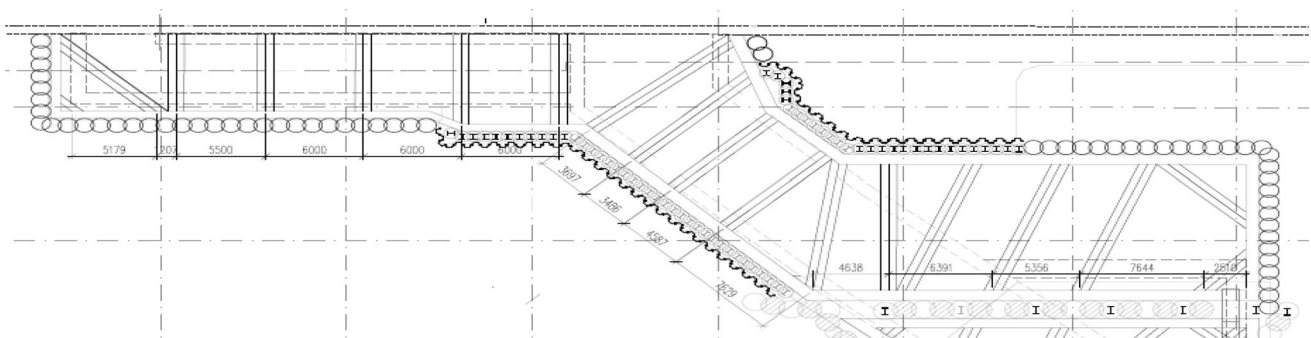
Due to the location of T222 on the fringe of the central business district (CBD), numerous stakeholders were involved with each one having different sets of requirements, including two public transport operators. On the north side, a linkway retaining wall abuts the existing underground EWL station, and on the south side it is 30 m away from Outram Road. This carriageway is one of the widely used roads leading into the CBD. It was necessary to meet the expectations and satisfy the requirements of stakeholders to facilitate the construction of new stations. Due to the close proximity to the Health Science Authority, existing MRT stations, residential and commercial developments, there were numerous restrictions on working hours, construction sequences, stringent monitoring



**Fig. 3** Soil profile and core box result at zone G

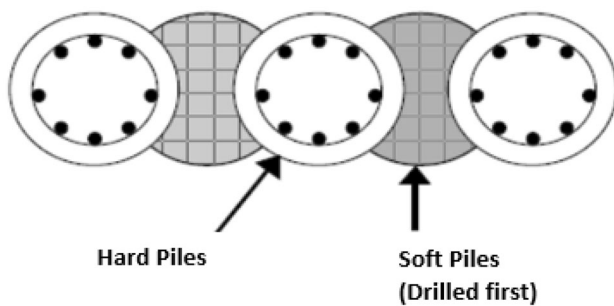


**Fig. 4** Location of zone G with nearby stakeholders



**Fig. 5** Layout plan of retaining wall of zone G





**Fig. 6** Hard bored pile and soft bored pile

requirements, etc. Stakeholder's expectations were managed by the early engagement of stakeholders in the planning phase (Fig. 4).

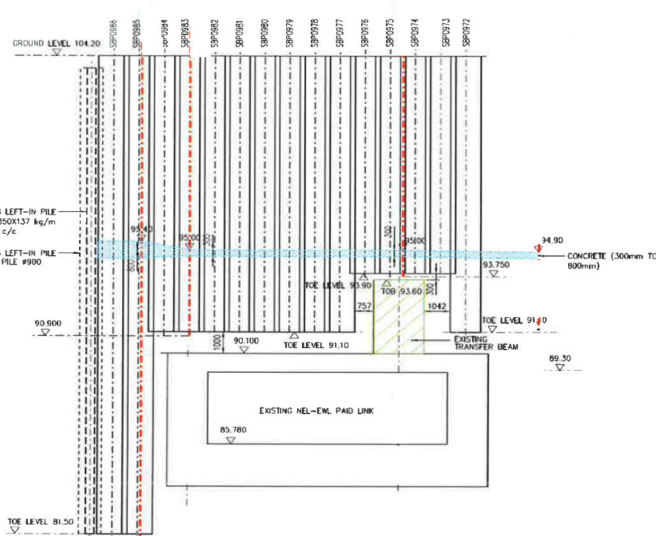
#### 4 Secant Bored Piling Works

Secant bored piles (SBP) were designed to form the temporary retaining wall system for the construction of zone G to minimise disturbance and vibrations to adjacent

structures (Fig. 5). The SBP wall is formed by constructing intersecting reinforced concrete piles [3]. The wall consists of overlapping hard and soft piles to form structural or cut-off walls and achieve required water tightness [4]. The SBPs are reinforced with either steel rebar or steel beams and are constructed by either drilling under mud or augering [5]. Soft piles are installed first, followed by hard piles placed between the soft piles once the latter gained sufficient strength (Fig. 6).

The toe level of the SBPs designed for zone G is 300 mm above the existing EWL–NEL linkway. During the construction, one of the major challenges in installation of SBPs as part of retaining wall system was to prevent the settlement of the sand during boring works, and to minimise the impact on the existing structures. During piling works, an unknown concrete slab of varying thickness (300–800 mm thick) was found at 9 m below ground level which further added to the challenge of constructing the zone G retaining wall.

It was necessary to cut the existing unknown concrete slab to make way for new SBPs. With this objective, a



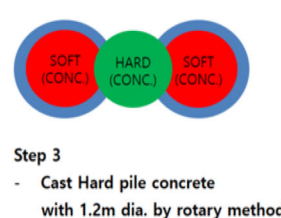
**Fig. 7** Obstructed of unknown concrete slab along SBP line

Type 1 (for soft pile) and Type 2 (for hard pile)

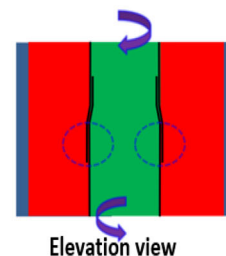


**Step 1**  
- Cast LSS as Soft pile with 1.4m dia.

**Step 2**  
- Cast Soft pile concrete with 1.2m dia.



**Step 3**  
- Cast Hard pile concrete with 1.2m dia. by rotary method



**Fig. 8** Method for construction of type 1 and 2 SBPs (plan and elevation)

boring rig with a coring bucket was deployed on-site to cut and remove the slab, and the SBP line was cleared of this obstruction. Figure 7 shows the extent of the unknown concrete slab (highlighted in blue) along the SBP line and a photo of the unknown slab which was cut to facilitate the construction of SBPs.

## 5 Sequence of Works

### 5.1 Original Sequence

Construction of the SBP wall is done in two stages: construction of soft piles followed by construction of hard piles [6]. Casing is installed into the ground to the fill material depth to prevent collapse of soil. However, for the construction of the SBP wall at zone G, this method was not applicable due to the presence of loose sand and concrete slab. Hence, different methods were tried on-site to overcome the challenges of SBP wall construction and mitigate the risks to adjacent structures.

### 5.2 Revised Sequence

To facilitate the construction of SBPs in newly discovered loose sand and concrete slab, a revised scheme was adopted to overcome the site challenges and to maintain the stability of surrounding structures. Type 1 was adopted for the construction of soft piles and type 2, 3 and 4 were implemented for the construction of hard piles.

#### 5.2.1 Type 1 (for soft piles)

Type 1 method was applied to soft piles of the SBP wall (step 1 and 2 in Fig. 8). In this method, 1.4-m-diameter casing was installed to the top of the unknown slab for boring to the level of the unknown slab. After the boring was completed, the existing unknown concrete slab was removed using a core bucket. Once the slab was removed, the borehole was backfilled with liquified stabilized soil (LSS) to the unknown slab level to minimise the settlement of surrounding structures and toppling of construction machinery. Subsequently, 1.2-m casing was installed until the designed toe level, followed by boring of the pile and casting of the actual SBP.

#### 5.2.2 Type 2 (for hard piles)

Figure 8 shows the method used for construction of hard piles. The type 2 method for hard pile (step 3) was not successful, as sand from the sides entered at the interface of soft piles and casing, causing a jam at the interface and making the extraction of casing difficult.

#### 5.2.3 Type 3 (for hard piles)

The soft piles were cast with LSS as elaborated in the type 1 method. Hard piles were also first cast with LSS following the same procedure of the soft pile. After LSS casting of soft and hard piles, soft piles were bored again with 1.2-m-diameter casing before the actual SBP was cast. Similarly, hard piles were also recast using 1.2-m-diameter casing. The sequence is shown in Fig. 9. Although this method was successful on-site, the progress rate was slow (0.3 piles per day) due to multiple boring.

#### 5.2.4 Type 4 (for hard piles)

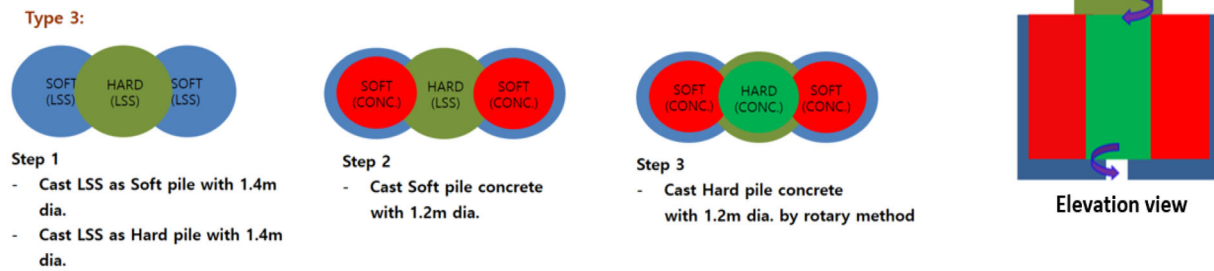
To overcome the challenge of slow productivity of the type 3 method, another method was proposed for construction of piles. In the type 4 method, two LSS piles (1.1-m diameter) were installed between the two piles as shown in Fig. 10. The procedure of installing the two LSS piles was similar to the type 1 method. In the next step, a 1.2-m-diameter casing was installed at the point of the hard pile and an actual hard pile was cast. This method was successful on-site, and the productivity rate (1 pile per day) was better than the type 3 method.

## 6 Instrumentation Monitoring Results

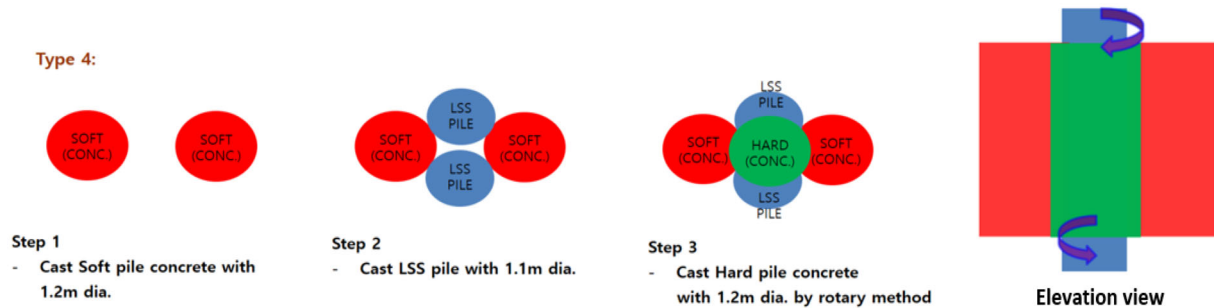
Construction in an urban environment requires a number of precautions to minimise or prevent damage to adjacent structures. Careful planning and engineering, pre-construction surveys, neighbouring building movement monitoring, vibration monitoring, coordination with neighbouring stakeholders, and overall due diligence all play a vital role in successful completion of a new construction project within an urban setting [7]. Before starting the retaining wall construction in the first railway protection zone, a comprehensive instrument monitoring scheme was installed in the nearby structures, including the existing EWL station, EWL track and the underground linkway connection between EWL and NEL stations [8] (Fig. 11).

Real-time monitoring was employed so that the movement of existing EWL and NEL tracks could be monitored closely at all times. Instruments in the existing station and linkway were also monitored periodically [9]. The movement trend of settlement markers, tilt meters and real-time prisms are shown in Figs. 12 and 13, which show the stable trends throughout the piling works.

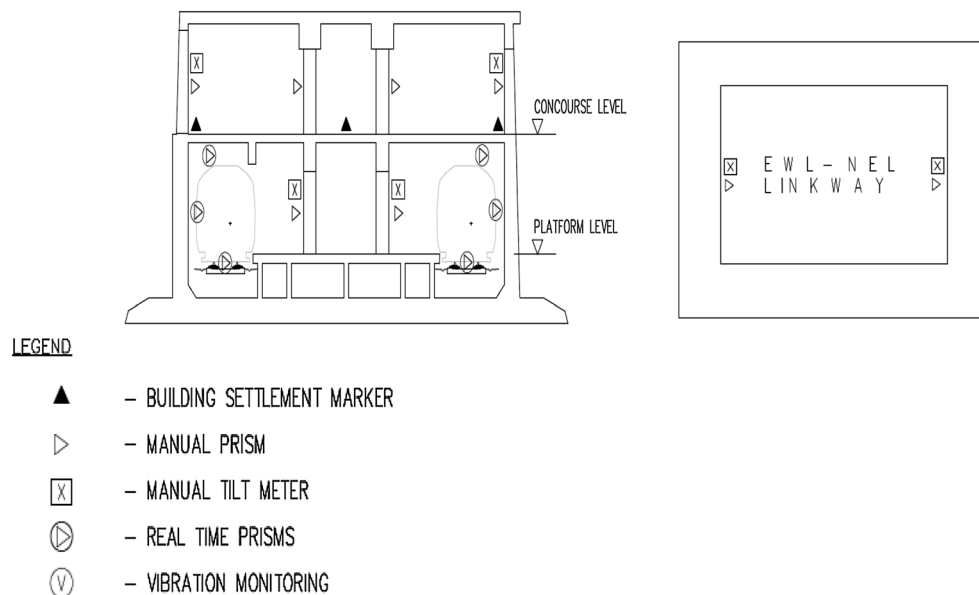
According to the instrument readings, settlement recorded in the EWL–NEL B3 linkway and EWL station was less than 2 mm which is less than the allowable limits. Moreover, from the reading of the tilt meter and prism, it is evident that the movement of the existing structures due to this construction was minimal.



**Fig. 9** Method for construction of type 3 SBPs (plan and elevation)



**Fig. 10** Method for construction of type 4 SBPs (plan and elevation)

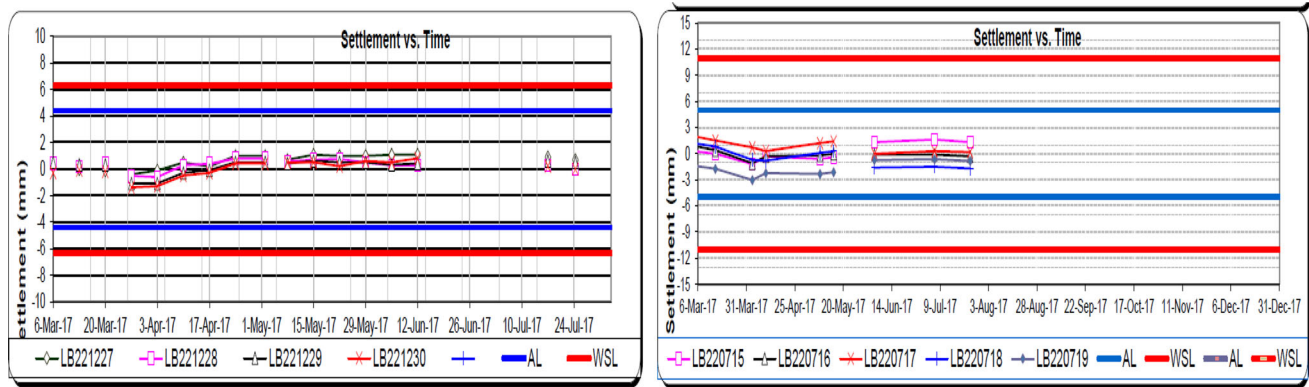


**Fig. 11** Instruments in the EWL station, trackside and linkway

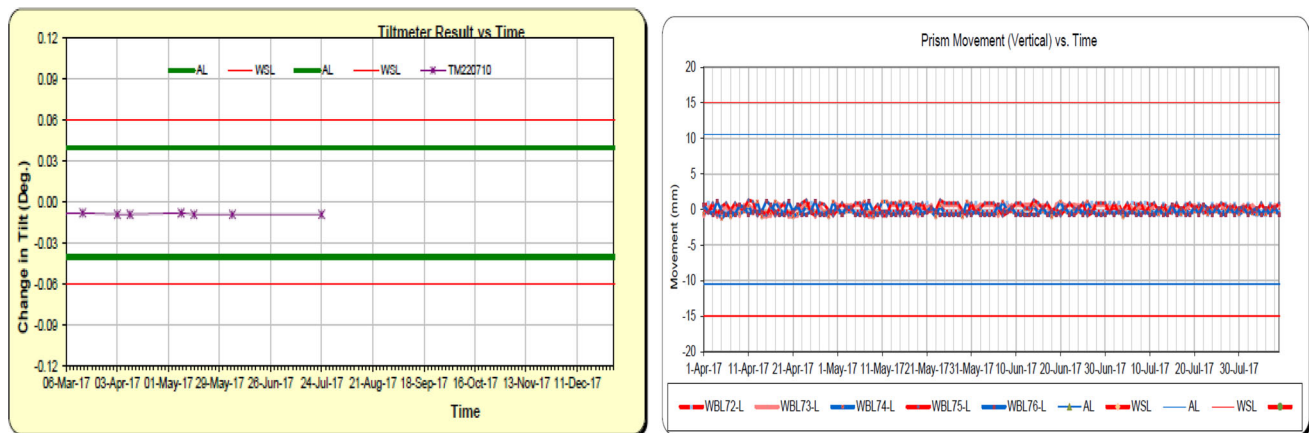
## 7 Supervision/Construction Control

Supervision is crucial for construction sites. The nature and level of supervision determine the workmanship on-site as well as the success of the consultant design. There have been many incidents where structural designs have failed

due to lack of proper supervision on-site. To ensure the quality of works and safety during these construction works, it was necessary to closely supervise the construction and workmanship [10]. Following are some of the ways by which supervision and construction control was achieved on-site:



**Fig. 12** Trend of settlement markers in the EWL–NEL B3 linkway (left) and EWL station (right)



**Fig. 13** Trend of tilt meter in the EWL station (left) and real-time prism movement in the EWL track way (right)

- Detailed survey of existing structures to verify the outline of existing structures and ensure that existing structures are not damaged during the construction works
- Identification and clear marking of underground existing structures before starting the construction works on-site
- Periodical site audits by management personnel to ensure the quality of supervision on-site.
- Construction of the SBP wall was done under the close supervision of qualified personnel or a representative to ensure compliance with construction drawings and approved method statements on-site.
- Monitoring records were reviewed by a design engineer periodically to validate the design assumptions

## 8 Conclusion

Construction in densely populated areas involves numerous risks to the locality. One of the biggest challenges in undertaking underground construction in a highly

urbanised environment is the impact of construction on adjacent structures. The deformation of ground should satisfy acceptable ground and existing structure settlement limits in order to limit the impact of new construction on existing structures. This paper summarised the mitigation measures for construction of secant bored piles above the existing underground linkway and adjacent to an existing MRT station. Various construction methods were deployed to enable the construction of hard and soft piles in sandy strata while maintaining the stability of the existing structures in the vicinity. It can be concluded that type 1, type 3 and type 4 methods can be used for the construction of SBPs in loose sand out, of which type 1 and type 4 methods are recommended due to a better productivity rate on-site. It was also observed that movements to the buildings due to secant bored piling in the vicinity can be reduced to a minimum provided that appropriate measures are applied to control ground movement. It is believed that lessons learnt from this project would give greater confidence for undertaking future underground developments in such challenging environments.

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